Modeling the Behavior of FCC Single Crystals under Shock Loading: Dislocation Dynamics Analysis

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Abstract

Understanding the dynamic response of materials under the effect of very high strain-rate shock loading, such as explosive deformation and high speed machining, is very important. However, current experimental capabilities cannot address the response of the materials at pressures larger than 1.0 Mbar. The aim of this work is to investigate using a multi-scale model, which includes discrete dislocation dynamics analysis, the materials response under the effect of high strain-rate shock loadings. Computer simulation analyses were carried out to characterize the mechanical behavior and the response of copper and aluminum single crystals to various types of extremely high strain rate shock loadings ranging from 10^6 to 10^8/s. The effect of material properties, loading conditions, shock pulse duration and peak pressure on the dynamic deformation and the failure modes were studied. Relaxed configurations using dislocation dynamics show formation of different types of dislocation and deformation patterns like dislocation cells and adiabatic shear bands.

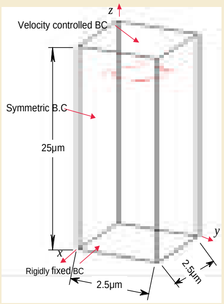
Introduction

It is very important to understand the response of metals to high strain rate loading. This type of dynamic events can take place in many applications such as, high speed machining, explosive deformation and high intensity laser interaction with solid targets, etc. When a solid material experiences high pressure shock loading, stresses that occur at the lattice level result in the generation and propagation of dislocations.

During the last decade, many experimental technique have been developed to examine the materials behavior under extreme conditions. Laser based experiments have been used to to analyze the shock wave phenomena in in single crystals. Electron microscopy technique is used is used to study the dislocation microstructures and patterns formed at different strain rate loading conditions. However, current experimental capabilities can not address the response of materials at pressures larger than 1.0 Mbar.

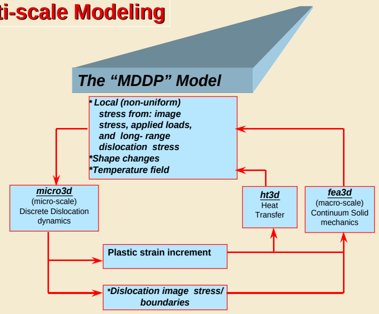
In our attempt to understand the metals response to high strain rate conditions, we use multiscale model which include 3D dislocation dynamics to study the interaction between shock waves and dislocations.

Computational Setup

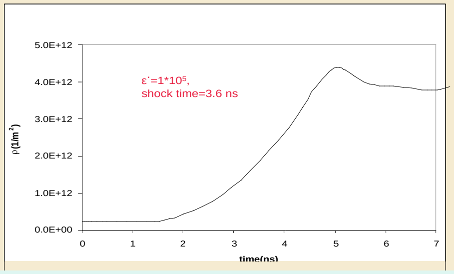


- Cu & Al single crystals
- Loading direction{0 0 –1}
- Initially
  - 8 Frank-Read loops - 4 different slip planes
  - Length of each source 3000 b
  - Periodic BC used in the DD part

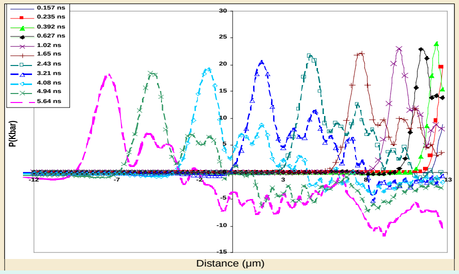
Multi-scale Modeling



Dislocation Density



Hydrostatic Pressure Profiles



Conclusions

- Attenuation of shock waves is caused by energy dissipation and shear modulus dependence on pressure.
- Dynamic tension occurs in the the shocked crystal as a result of the dislocations motion and propagation.
- There are three regions in the dislocation history curves
  1- no dislocation-shock waves interaction region.
  2- dislocation-shock waves interaction region.
  3- dislocation density saturation region.